Behavior of Green Sturgeon Near a Model Louver System in a Laboratory Flume, and an Assessment of Predation Risk: Annual Report Year 2

Prepared for: The California Department of Water Resources Bay-Delta Office

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1.0 Introduction

Throughout the Sacramento-San Joaquin watershed, fish protection and/or fish guidance systems are used to reduce or eliminate the entrainment of fishes through water projects such as water diversion facilities. The efficacy of these devices and the behavior of fishes near them are poorly understood for some species, particularly for threatened native fishes such as Green Sturgeon (*Acipenser medirostris*). Therefore, a model louver system simulating conditions at the John E. Skinner Delta Fish Protective Facility (SDFPF) of the State Water Project (SWP) and the Tracy Fish Collection Facility (TFCF) of the Central Valley Project (CVP) was constructed at the J. Amorocho Hydraulics Laboratory (JAHL), and experiments were initiated to quantify the successful bypassing of juvenile Green Sturgeon at different sizes and ages. Additionally, since little or no data on the predators or predation rates of juvenile Green Sturgeon exist, the development of a predation assessment experiment was initiated.

The results presented throughout this report are preliminary results gathered over different testing conditions, and at various stages of experimental development. Therefore, they are not meant for distribution, nor should they be interpreted as final outcomes, since results could change pending the acquisition of additional data. These data will be used to inform the experimental design for upcoming test seasons and to ensure that all modifications needed for appropriate experimentation have been identified and incorporated. This project year we conducted 232 total trials with the experimental louver at multiple sweeping flows, water temperatures, photophases, and Green Sturgeon size-classes, as well as eight replicated trials of predation of Largemouth Bass on Green Sturgeon.

2.0 Experimental Set-up and Controls

2.1. Flume, pumping system, and flow controls

A true to scale schematic of the top view of the experimental flume is shown in Figure 1(a) and the flume cross-section is shown in Figure 1(b). The flume is 80 feet long, 6.9 feet wide, 4.5 feet high with zero bed slope. Utilizing the downstream tail gate as datum (x=0 feet), the louver array's leading edge is at x=40.3 feet. The louver is 22.2 feet long, set at a 15 degree angle to the sweeping flow. Figure 1(a) also contains the relative locations of the structural support bars and velocity measurement cross-sections.

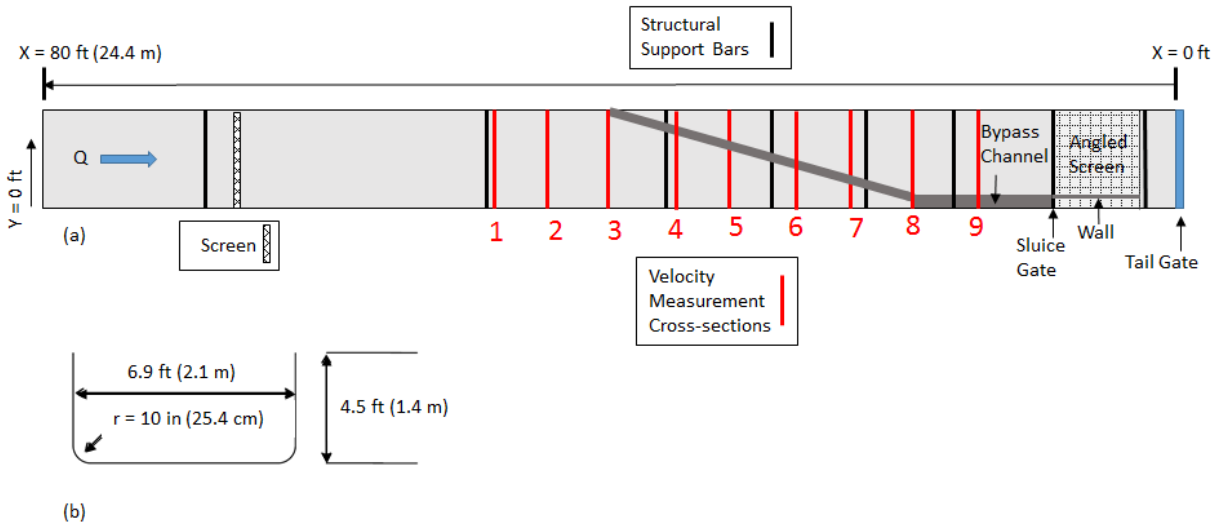

Figure 1. (a) Top view schematic of flume and louver configuration (to scale), (b) flume cross-section.

The pumping system, consisting of two single speed pumps and one variable speed pump, provides a pumping capacity of over 85 cfs. The variable frequency drive (VFD) allows for variable flow output from the largest pump, as required to meet the study velocity goals of 1, 2, and 3 ft/s. A remote control and remote display has been linked to the VFD for increased safety during operation of the pumping system. A sluice gate in the bypass channel allows for regulation of the bypass channel flow velocities, which are maintained at a ratio of 1.2:1 when compared to the main channel velocities. A winch operated tail gate controls water depth in the flume. There are two sharp crested underflow gates upstream of the screen to stabilize flows, one three feet upstream of the screen, and one at the interface of the inlet chamber and flume. The screen is required to keep fish from entering the inlet area, and, as mentioned in the Year 1 Annual Report, the underflow gates serve to eliminate low velocity refugia caused by the screen. The gates are equally sized, and block the top 11 inches of the flume. Figure 2 contains a schematic of the flume flow direction and flow controls.

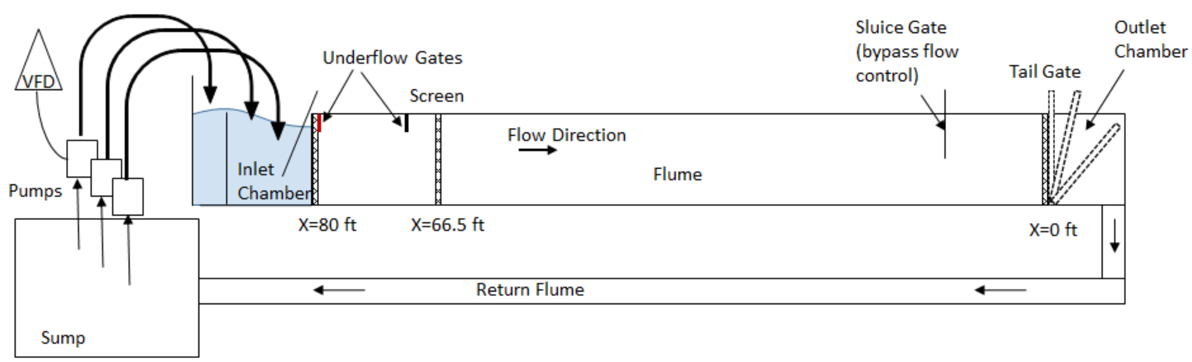

Figure 2. Flume flow direction and control schematic.

A 3-horsepower discharge pump was installed and plumbed to the water storage sump to allow for efficient replacement of sump water as needed for water quality. Work was performed on the water temperature control system to repair functionality following failure of the chiller pump and chiller unit during July of 2016. This resulted in approximately a week-long delay during the window of experiments with small size-class Green Sturgeon. Additionally, a failed welded seam in the flume's tail-tank was repaired, the proper sized power transfer wiring to the well, and associated plumbing that supplies well water to the flume's sump was relocated and replaced.

3.0 Hydraulic Measurements

3.1. Measurement of velocity fields

Three-dimensional velocities were measured under the 1 ft/s flow condition. Velocities were measured at nine cross-sections (Figure 1a) in the experimental section of the flume. The number of cross-sections measured was increased to nine from the five used in the Year 1 plan in order to better describe the hydraulic conditions in the experimental flume. Cross-sections were spaced at 52-inch intervals. Cross-section 3 is located at the leading upstream edge of the louver and cross-section 8 is located at the trailing edge. Measurements were made with a SonTek 10 MHz ADV probe capable of measuring the 3-dimensional velocities at 25 Hz in a 0.25 cubic centimeter volume. Accuracy of the device is ±1% of the measured velocity. Under field conditions, variations in velocity occur at a fixed location in part due to turbulence, obstacles in the flow and unsteadiness in the boundary conditions. In order to account for these natural velocity variations, all measurements of 3-dimensional velocity fields were observed for a minimum of 30 seconds, and time-averaged to assess flow stability and velocity magnitude.

Measurement locations were kept equal with respect to depth (as measured from the flume bottom) and distance from the wall for all cross-sections in the flume. The measurement pattern was altered in the bypass channel for cross-sections 8 and 9. Measurements were taken over a denser grid lower in the water column in order to provide a more detailed map of velocities expected to be most experienced by Green Sturgeon. Additionally, measurements were taken 3-inches from the louver face (cross-sections 3 through 8) at multiple depths to allow for interpretation of near-louver hydrodynamics. Near-louver hydrodynamics will later be compared to observations of sturgeon behavior. Three dimensional velocity measurement locations, and velocity fields for each cross-section are shown in Figures 3-19. Velocity fields are represented as contour plots of the stream-wise (x-directional) velocities overlaid with vectors representing the cross-sectional (y-z plane) velocities. Note that in each figure, the y-axis represents depth, with the datum, $y = 0$, representing the bottom of the flume. It is expected that velocities will be low near the flume bottom and edge, as bed friction completely retards flow at these interfaces. Velocity initially increases rapidly with vertical distance from the bed before leveling off as it reaches the maximum value. For conditions within the flume, average velocity typically occurs at 60% of the total water depth, when measured from the bottom. In the following sub-sections of Section 3.1, there are several graphs, one for each cross-section, containing velocity contours for the stream-wise velocity component and velocity vectors for the velocity component in the cross-section. These velocities in the cross-section are termed cross-sectional velocities and are perpendicular to the stream-wise velocities.

3.1.1. Cross-section 1

Figure 3 contains the velocity measurement locations for cross-sections 1 and 2, upstream of the louver. Figure 4 contains the velocity field for cross-section 1. Please refer to Figure 1 for the location of cross-sections along the length of the flume. The velocity contours show that 1 ft/s average velocity is maintained during experiments. Inspection of cross-section 1's velocity vectors reveals little cross-sectional velocity in that region. Flow is therefore stabilized prior to cross-section 1, and the louver does not appear to affect the flow field in the region of the most upstream cross-section.

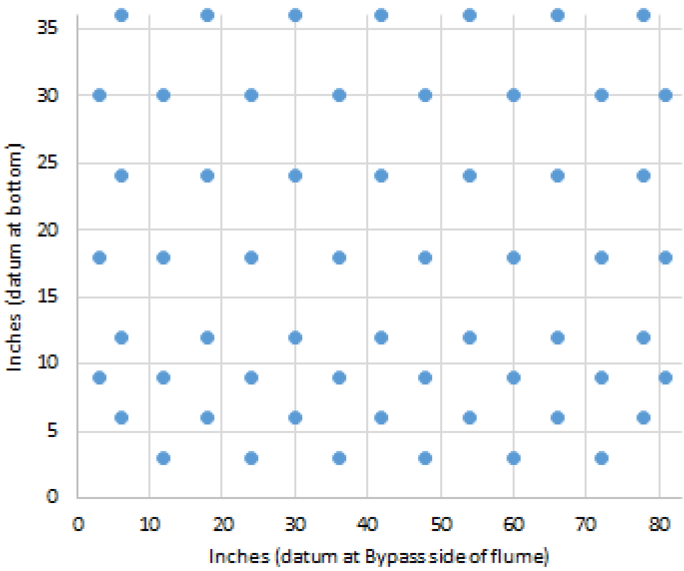

Figure 3. Measurement grid for cross-sections 1 and 2, z (depth) datum is the flume bottom, y (cross-wise) datum is the east flume wall (bypass side of flume).

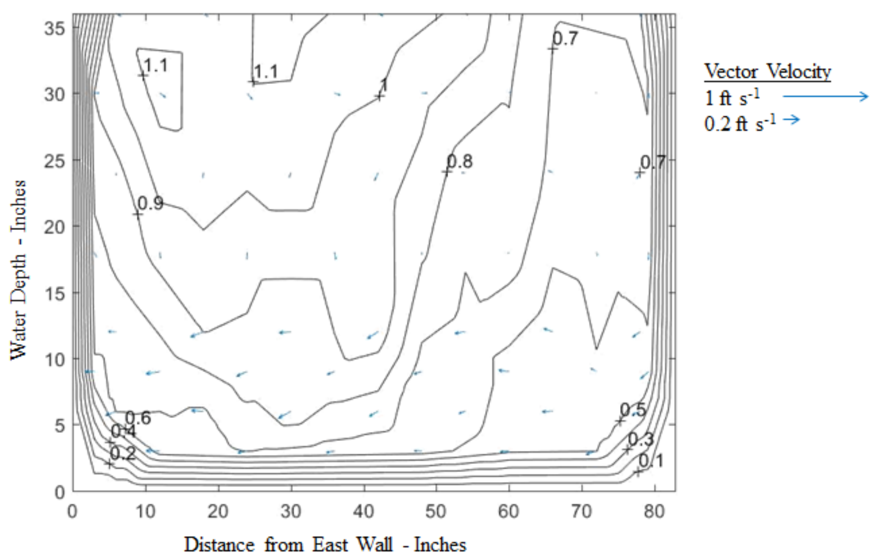

Figure 4. Cross-section 1, velocity contours in x-direction (stream-wise) and velocity vectors in y-z plane. Depth measured from flume bottom.

3.1.2. Cross-section 2

The velocity measurement locations for cross-section 2 are the same as those in cross-section 1, as shown in Figure 3. Figure 5 contains the velocity field for cross-section 2. The velocity contours are similar to those of cross-section 1, as are the cross-sectional velocities whose magnitude is small in relation to the stream-wise velocity.

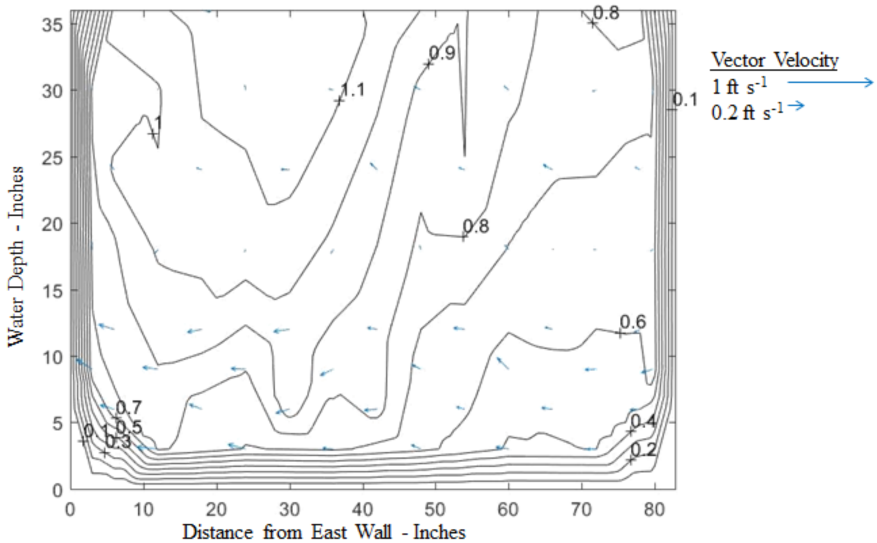

Figure 5. Cross-section 2, velocity contours in x-direction (stream-wise) and velocity vectors in y-z plane. Depth measured from flume bottom.

3.1.3. Cross-section 3

The velocity measurement locations for cross-section 3 are shown on Figure 6, and the velocity field is displayed on Figure 7. Cross-section 3 is at the upstream edge of the louver, such that flow is completely obstructed where the louver meets the western wall of the flume. Average stream-wise velocities at cross-section 3 do not appear significantly affected by the louver; however, increased cross-sectional velocities can be observed at the right of the plot in Figure 7. The increase is due to re-distribution of flow at the point of the obstruction.

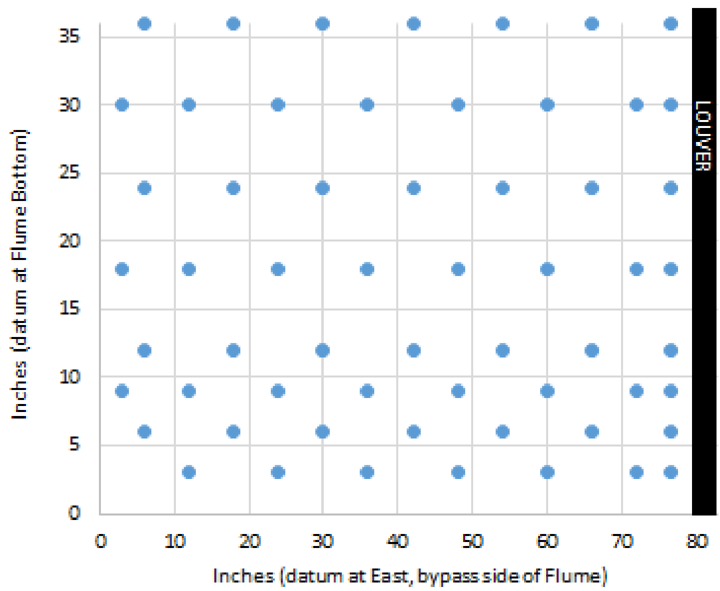

Figure 6. Measurement grid for cross-section 3, z (depth) datum is the flume bottom, y (cross-wise) datum is the east flume wall (bypass side of flume).

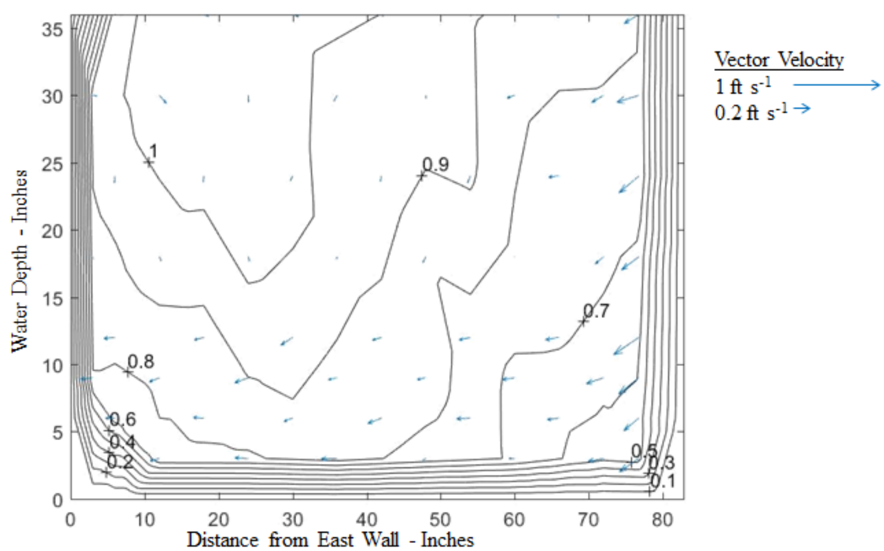

Figure 7. Cross-section 3, velocity contours in x-direction (stream-wise) and velocity vectors in y-z plane. Depth measured from flume bottom.

3.1.4. Cross-section 4

Figure 8 contains the velocity measurement locations for cross-section 4. The velocity field is displayed in Figure 9. The louver is sufficiently away from the far wall such that velocity measurements were taken in front of and behind the louver face. Velocity contours show the depth of the average velocity magnitude is maintained at roughly 60% of the total water depth. Velocity vectors on Figure 9 suggest flow is directed vertically downward behind the louver. Vectors in the bottom 12 inches of the water column, and at least 3 inches from the louver face suggest flow in that region moves away and down from the louver face.

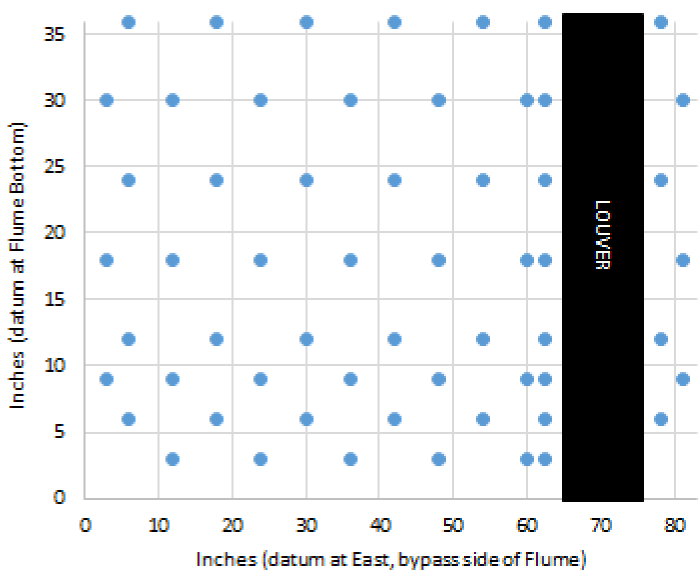

Figure 8. Measurement grid for cross-section 4, z (depth) datum is the flume bottom, y (cross-wise) datum is the east flume wall (bypass side of flume).

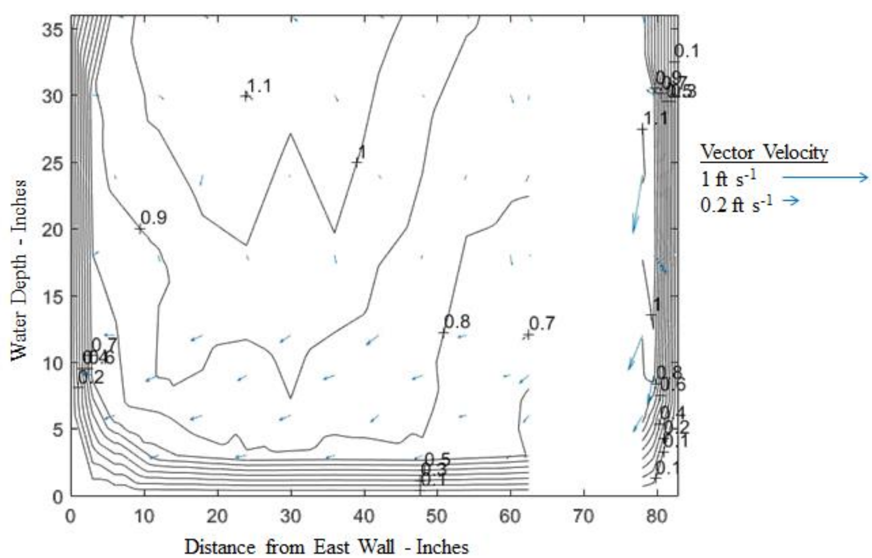

Figure 9. Cross-section 4, velocity contours in x-direction (stream-wise) and velocity vectors in y-z plane. Depth measured from flume bottom.

3.1.5. Cross-section 5

The velocity measurement locations and the velocity field for cross-section 5 are shown on Figures 10 and 11 respectively. The velocity contours for cross-section 5 maintain the expected distribution of stream-wise velocity with depth. The cross-sectional velocities behind the louver tend to direct vertically downward but with smaller magnitude than in cross-section 4. The decreased velocity magnitude results from increased flow area behind the louver and less abrupt reflection off the far wall of the flume. Cross-sectional flows in front of the louver face and within the bottom 12 inches of the water column are directed down and away from the louver face.

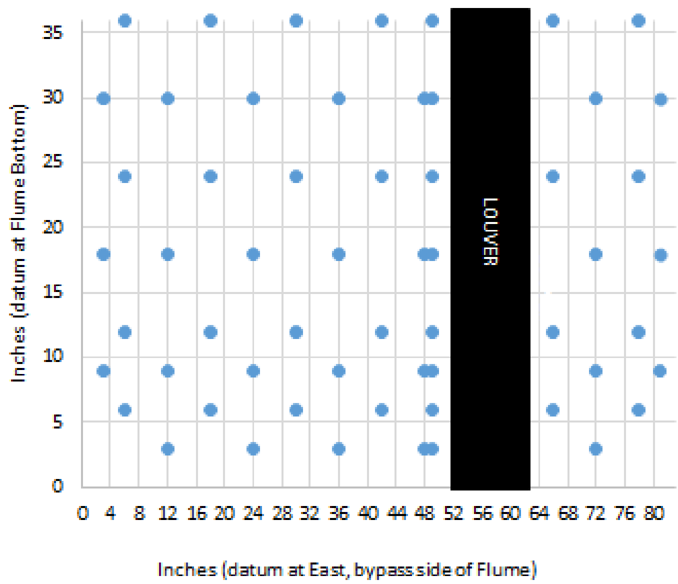

Figure 10. Measurement grid for cross-section 5, z (depth) datum is the flume bottom, y (cross-wise) datum is the east flume wall (bypass side of flume).

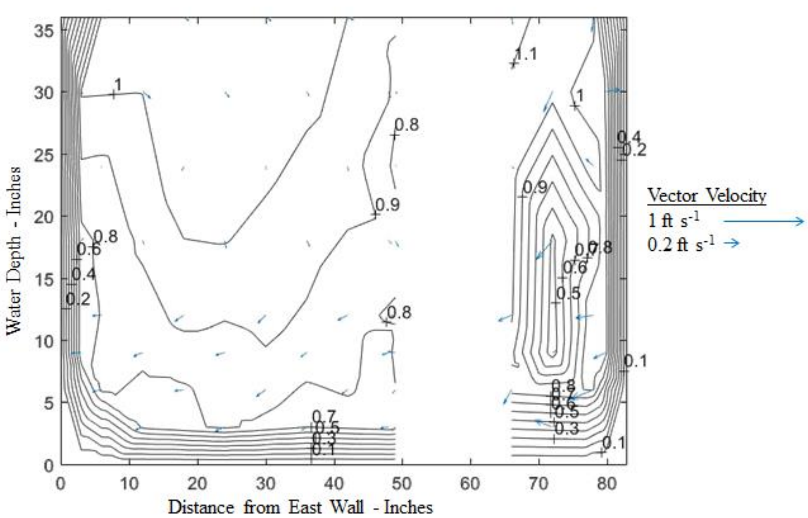

Figure 11. Cross-section 5, velocity contours in x-direction (stream-wise) and velocity vectors in y-z plane. Depth measured from flume bottom.

3.1.6. Cross-section 6

Figure 12 contains the velocity measurement locations for cross-section 6, and the velocity field is displayed in Figure 13. The bottom 12 inches of the water column has larger and more uniform cross-sectional velocities than those in the upper water column. Energy loss, and the consequent slight reduction in water depth created by the obstruction effect of the louver, may contribute to the occurrence of 1 ft/s velocities lower in the water column than in the more upstream cross-sections.

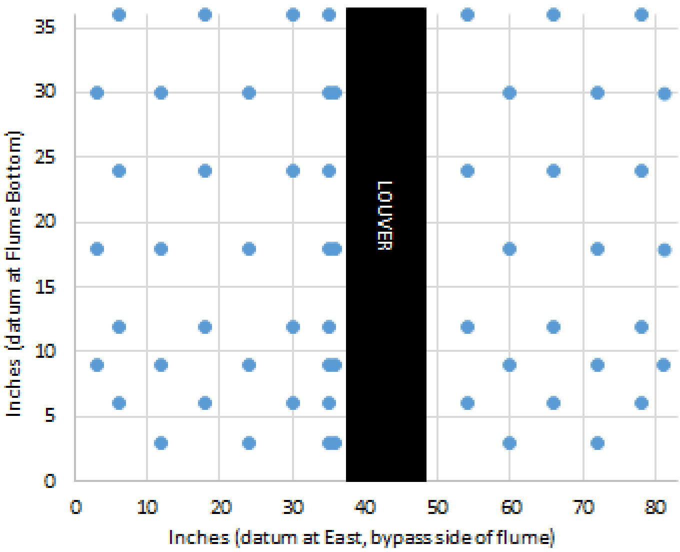

Figure 12. Measurement grid for cross-section 6, z (depth) datum is the flume bottom, y (cross-wise) datum is the east flume wall (bypass side of flume).

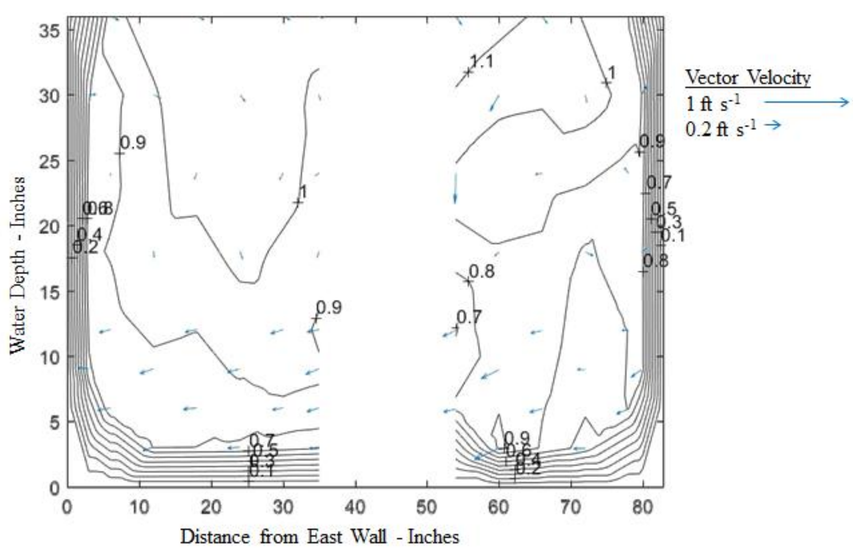

Figure 13. Cross-section 6, velocity contours in x-direction (stream-wise) and velocity vectors in y-z plane. Depth measured from flume bottom.

3.1.7. Cross-section 7

The velocity measurement locations for cross-section 7 are shown in Figure 14, and the velocity field is displayed in Figure 15. Again, the louver may contribute to energy loss, depth reduction, and the decrease in water depth, which cause the average water velocity to occur closer to the flume bottom. The vectors on Figure 15 show that the cross-sectional velocities behind the louvers are less than those on the other side of the louvers due to the larger flow area behind the louvers. Again, the cross-sectional velocities are larger in the bottom 12 inches of water depth.

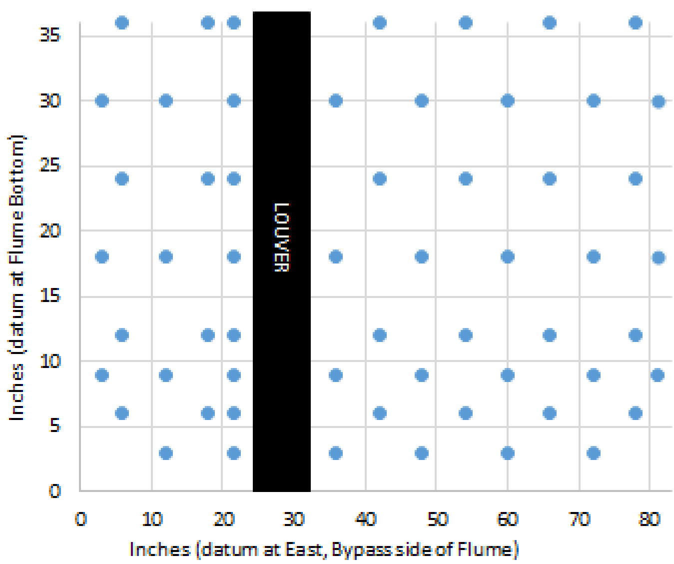

Figure 14. Measurement grid for cross-section 7, z (depth) datum is the flume bottom, y (cross-wise) datum is the east flume wall (bypass side of flume).

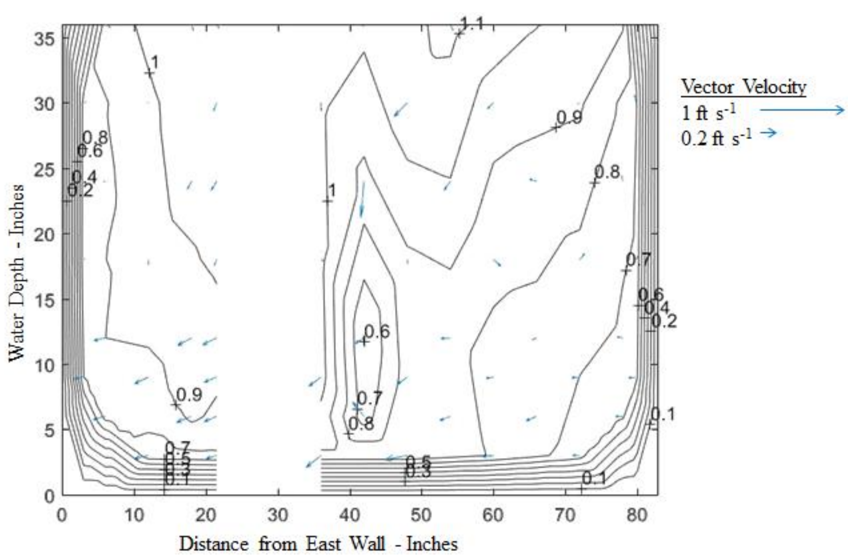

Figure 15. Cross-section 7, velocity contours in x-direction (stream-wise) and velocity vectors in y-z plane. Depth measured from flume bottom.

3.1.8. Cross-section 8

The velocity measurement locations for cross-section 8, and the velocity field are displayed in Figures 16 and 17, respectively. Cross-section 8 is at the entrance to the bypass channel. The contours of stream-wise velocity portray the rapidity with which the velocity increases from 0 at the flume wall, to its maximum (1.3 ft/s) within the bypass. The maximum velocity occurs lower in the water column within this constricted, turbulent area compared to the more open cross-sections upstream. Testing of the bypass channel velocity control underflow weir confirmed that average stream-wise velocity was 1.2 ft/s. Further investigation is required to determine the contribution of turbulence to the variation in flow velocities within this cross-section. Despite the averaging of 30-second data measured at 25 Hz, variability of turbulent flow can cause instantaneous velocities to be much larger or smaller than the average (Gordon et al. 2004). Cross-section velocity vectors indicate that flow is still directed down and away from the louver.

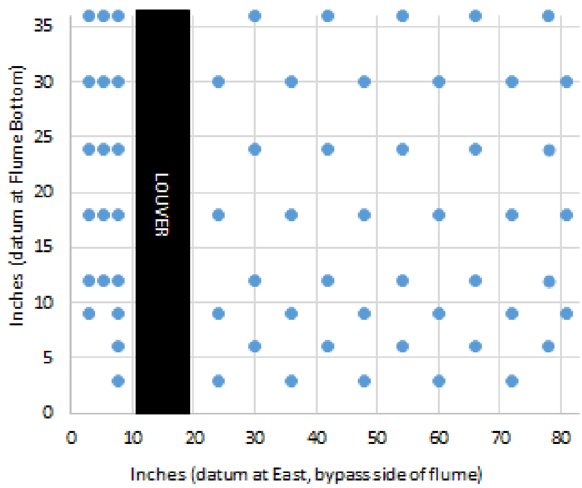

Figure 16. Measurement grid for cross-section 8, z (depth) datum is the flume bottom, y (cross-wise) datum is the east flume wall (bypass side of flume).

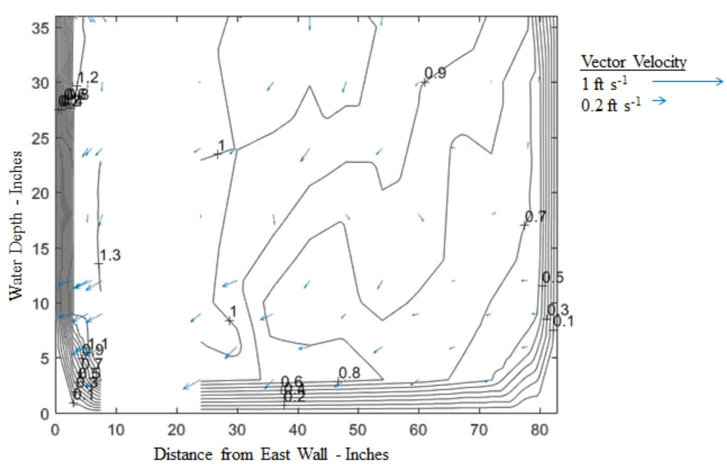

Figure 17. Cross-section 8, velocity contours in x-direction (stream-wise) and velocity vectors in y-z plane. Depth measured from flume bottom.

3.1.9. Cross-section 9

Cross-section 9 was the final cross-section measured, and exhibits similar hydrodynamic patterns to cross-section 8. The velocity measurement locations and the velocity field are shown on Figures 18 and 19, respectively. Again, the rapidity with which the velocity changes from 0 at the boundaries, to the maximum measure of 1.3 ft/s in the bypass is shown in the density of the contours. Cross-sectional velocity magnitudes are smaller at cross-section 9 than for cross-section 8 as the flow has begun to stabilize and orient more strongly stream-wise.

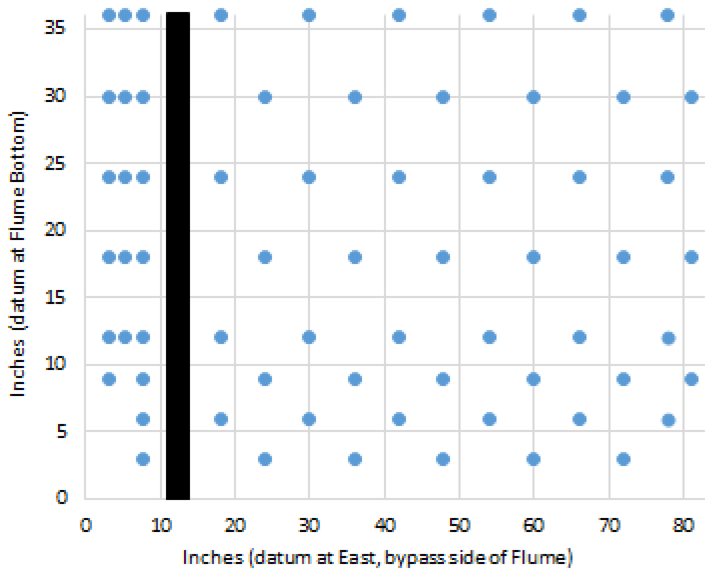

Figure 18. Measurement grid for cross-section 9, z (depth) datum is the flume bottom, y (cross-wise) datum is the east flume wall (bypass side of flume).

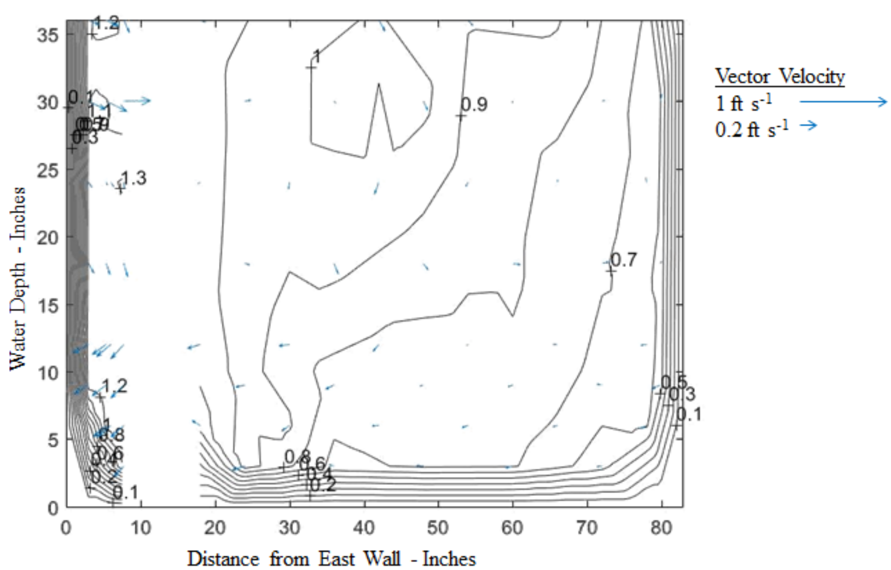

Figure 19. Cross-section 9, velocity contours in x-direction (stream-wise) and velocity vectors in y-z plane. Depth measured from flume bottom.

3.2. Future planned measurements

Three-dimensional velocities will be measured, and velocity contour plots will be generated for the 2 and 3 ft/s velocities over the duration of the study. At each cross-section, the current measurement configuration provides 8 measurements, at depths of 3, 6, 9, 12, 18, 24, 30 and 36 inches, located 3 inches from the louver face. We propose to take additional measurements in the final year as dictated by study results such as fish contact and impingement locations.

4.0 Model Louver Fish Performance Experiments

4.1. Experimental design

For each individual trial, 60 naïve juvenile Green Sturgeon were transported to the JAHL from the Center for Aquatic Biology and Aquaculture (CABA) in aerated, insulated coolers. Fish were introduced into the flume using an acclimation tank fitted with a release tube and equipped with flowing water from the flume's head-tank. Sump water replaced the volume of the acclimation tank approximately every 10 min. When operating, the water was continuously re-oxygenated as it fell from the flume into the sump, then over the highest weir in the head-tank. The tube release mechanism consisted of an 8-in diameter polyvinylchloride pipe that was 6.5 feet long (198 cm), modified with a widened inlet at the top of the pipe and a 45 degree angled extension at the bottom of the pipe, making the fish exit point parallel to the flume's floor. The tube release mechanism could be raised or lowered to remove it from the flume during experimental trials, and was affixed to an acclimation holding tank above the flume via a flexible collar. Once the flow velocity stabilized at the beginning of a trial, the pipe was lowered into the flume and an operable gate in the acclimation tank was opened to allow water and fish to pass into and through the pipe. After all fish passed through the tube, it was raised out of the flow field to a stationary position (approximately 3-5 minutes).

Seven underwater cameras were placed within the flume to record downstream fish movement, louver interactions (contacts, impingement, and entrainment), fish passage, and rheotaxis into the bypass channel. There were five cameras along the face of the model louver, one fish-eye camera to record fish passage into the louver-region of the flume, and one camera to record fish passage into the bypass channel. Experimenters recorded the timing of bypass events. Fish were collected from the downstream portion of the bypass channel, after passing through the rear sluice gate, with dip-nets and placed into holding tanks. Any fish that were entrained through the louver were collected separately and placed into a separate holding tank. Each trial lasted for 90 minutes after the release of fish into the flume, and any fish remaining in the flume at the end of the trial were collected separately from those that were bypassed or entrained. The mass, total length (TL), and fork length (FL) were measured for a subset of fish collected at each endpoint. Any injuries or abnormalities were noted. Daytime trials were conducted under ambient light conditions between the hours of 0800 and 1600. Nighttime trials were conducted in dark conditions between sunset (variable) and 0100, with limited infrared light to allow experimenters to navigate safely, and periodic localized full-spectrum light to collect juvenile fish from the bypass channel. Note that during all experiments the bypass channel was covered from the sluice gate to the downstream edge of the louver to better mimic the enclosed bypass channels of the fish protective facilities at TFCF and SDFPF.

4.2. Preliminary Results

4.2.1. Trials completed

Experiments were conducted between June 28 and Oct 7 2016, when the juvenile sturgeon were at the appropriate size classes. We conducted 232 experimental trials (Table 1), including eight replicates of all treatments for both the large size class (28 - 34 cm TL) and medium size class (16 - 22 cm TL) Green Sturgeon. Eight replicates of each sweeping flow were conducted for the small size class (6 - 12 cm TL) during the day at 19°C, and an additional sixteen replicates were conducted for the small size class at 2 ft/s. In each trial, up to twelve individuals from each endpoint (entrained, bypassed, or remaining in flume) were weighed and measured to ensure juvenile Green Sturgeon were within the targeted size class (Table 2).

Table 1. Number of experimental trials conducted in 2016 in a model louver system at the J. A Hydraulics Laboratory at UC Davis. Experimental treatments were designed using a full factorial design of temperature (19°C and 12°C), photophase (Day and Night), sweeping water velocity (1, 2, and 3 ft/s), and size class (Small, Medium, and Large).

Small GS (6 – 12 cm TL)				
		1 ft/s	2 ft/s	3 ft/s
19°C	Day	8	8	8
	Night	0	8	0
12°C	Day	0	8	0
	Night	0	0	0
Medium GS (16 – 22 cm TL)				
		1 ft/s	2 ft/s	3 ft/s
19°C	Day	8*	8	8
	Night	8	8	8
12°C	Day	8	8	8
	Night	8	8	8
Large GS (28 – 34 cm TL)				
		1 ft/s	2 ft/s	3 ft/s
19°C	Day	8	8	8
	Night	8	8	8
12°C	Day	8	8	8
	Night	8	8	8

* four of eight trials removed from analysis due to inconsistencies in experimental protocol

Table 2. Mean and standard deviation (SD) of total length (TL, cm) and mass (g) of measured individuals across eight trials for experimental treatment. Treatments were planned using a full factorial design of temperature (19°C and 12°C), photophase (Day and Night), sweeping water velocity (1, 2, and 3 ft/s), and size class (Small, Medium, and Large). In each trial, 60 naïve individuals were introduced into the flume, and length and mass of a minimum of 12 individuals were measured for each of three possible endpoints (entrained through louver, bypassed, or remaining in flume), resulting in a minimum of 12 and a maximum of 36 measured fish in each treatment.

		1 ft/s		2 ft/s		3 ft/s	
Small GS (6 - 12 cm TL)							
		TL (SD)	mass (SD)	TL (SD)	mass (SD)	TL (SD)	mass (SD)
19°C	Day	9.2 (1.2)	4.3 (1.6)	10.1 (2.1)	5.3 (2.4)	10.3 (1.9)	5.9 (3.1)
	Night	--	--	11.6 (1.4)	7.5 (2.5)	--	--
12°C	Day	--	--	11.7 (1.1)	7.7 (1.9)	--	--
	Night	--	--	--	--	--	--
Medium GS (16 - 22 cm TL)							
		TL (SD)	mass (SD)	TL (SD)	mass (SD)	TL (SD)	mass (SD)
19°C	Day	19.0 (2.2)	28.8 (9.5)	19.1 (1.7)	28.7 (7.2)	17.7 (1.5)	22.9 (5.4)
	Night	19.2 (1.9)	29.0 (7.4)	19.3 (1.9)	29.1 (7.7)	18.7 (1.7)	27.4 (7.0)
12°C	Day	18.8 (2.5)	30.3 (11.5)	19.4 (2.4)	32.7 (11.8)	19.2 (2.3)	30.8 (10.5)
	Night	18.7 (2.3)	29.6 (10.9)	19.2 (1.8)	31.1 (8.2)	19.0 (2.4)	31.0 (11.4)
Large GS (28 - 34 cm TL)							
		TL (SD)	mass (SD)	TL (SD)	mass (SD)	TL (SD)	mass (SD)
19°C	Day	29.4 (1.5)	88.3 (15.0)	29.4 (1.5)	88.0 (16.1)	29.7 (1.7)	90.9 (16.5)
	Night	28.7 (2.8)	83.7 (23.7)	28.9 (2.8)	82.9 (23.3)	29.0 (2.4)	84.7 (22.4)
12°C	Day	33.2 (3.7)	147.0 (47.2)	32.8 (3.4)	140.6 (48.5)	31.9 (2.1)	126.8 (24.7)
	Night	31.6 (3.5)	129.2 (51.4)	32.3 (3.2)	134.5 (41.1)	31.6 (2.6)	125.1 (31.0)

4.2.2. Bypass rates

In general, most Green Sturgeon moved into the bypass channel, while some remained within the experimental flume during the entire trial (Table 3, Figure 20). Very few fish were entrained through the louver. As expected, most entrainments occurred for the smallest size class and at the highest flow velocities (Figure 21). It is interesting to note that during the day, for both the large and small size-classes at 2 ft/s, there was a low bypass rate and high proportion of fish remaining in the flume after the 90 minute trial. We hypothesize that at these velocities fish are stimulated to swim into the flow, and thus are more likely to remain in the flume channel. At 1 ft/s they are more likely to explore and move voluntarily downstream into the bypass channel, while at 3 ft/s the velocity is greater than their sustained swimming speeds and they are pushed downstream into the bypass channel.

Table 3. Mean and standard deviation (SD) of the percentage of Green Sturgeon in each of three possible end points (collected in the bypass channel, entrained through the model louver, or remained within the flume) after each completed trial. Eight replicate trials (except where noted in Table 1) of 60 naïve fish were conducted for each treatment. Experimental treatments were planned using a full factorial design of temperature (19°C and 12°C), photophase (Day and Night), sweeping water velocity (1, 2, and 3 ft/s), and size class (Small, Medium, and Large).

	Water Velocity	Photophase	N Bypassed	N Entrained	N Remaining
Large (6- 12 cm TL)					
12°C	1 ft/s	Day	76.9% (26.2%)	0.0% (0.0%)	23.1% (26.2%)
	1 ft/s	Night	89.0% (6.5%)	0.0% (0.0%)	11.0% (6.5%)
	2 ft/s	Day	36.9% (13.3%)	0.0% (0.0%)	63.1% (13.3%)
	2 ft/s	Night	83.5% (8.7%)	0.0% (0.0%)	16.5% (8.7%)
	3 ft/s	Day	100% (0.0%)	0.0% (0.0%)	0.0% (0.0%)
	3 ft/s	Night	99.4% (1.2%)	0.0% (0.0%)	0.6% (1.2%)
19°C	1 ft/s	Day	81.7% (10.5%)	0.0% (0.0%)	18.3% (10.5%)
	1 ft/s	Night	96.0% (3.6%)	0.0% (0.0%)	4.0% (3.6%)
	2 ft/s	Day	40.0% (9.3%)	0.0% (0.0%)	60.0% (9.3%)
	2 ft/s	Night	90.6% (4.7%)	0.0% (0.0%)	9.4% (4.7%)
	3 ft/s	Day	93.8% (6.0%)	0.0% (0.0%)	6.3% (6.0%)
	3 ft/s	Night	100% (0.0%)	0.0% (0.0%)	0.0% (0.0%)
Medium (16 - 22 cm TL)					
12°C	1 ft/s	Day	79.2% (11.9%)	0.0% (0.0%)	20.8% (11.9%)
	1 ft/s	Night	98.3% (1.8%)	0.0% (0.0%)	1.7% (1.8%)
	2 ft/s	Day	46.0% (20.0%)	0.0% (0.0%)	54.0% (20.0%)
	2 ft/s	Night	94.0% (4.0%)	0.0% (0.0%)	6.0% (4.0%)
	3 ft/s	Day	98.5% (1.1%)	0.6% (0.9%)	0.8% (0.9%)
	3 ft/s	Night	98.3% (1.5%)	1.0% (0.9%)	0.6% (0.9%)
19°C	1 ft/s	Day	85.4% (5.0%)	0.0% (0.0%)	14.6% (5.0%)
	1 ft/s	Night	91.7% (8.1%)	0.0% (0.0%)	8.3% (8.1%)
	2 ft/s	Day	55.4% (4.2%)	0.0% (0.0%)	44.6% (4.2%)
	2 ft/s	Night	90.6% (6.7%)	0.0% (0.0%)	9.4% (6.7%)
	3 ft/s	Day	99.4% (0.9%)	0.6% (0.9%)	0.0% (0.0%)
	3 ft/s	Night	99.6% (0.8%)	0.4% (0.8%)	0.0% (0.0%)
Small (6 - 12 cm TL)					
12°C	2 ft/s	Day	89.0% (8.1%)	1.7% (1.3%)	9.4% (9.0%)
19°C	1 ft/s	Day	59.2% (13.0%)	1.3% (1.7%)	39.6% (12.4%)
	2 ft/s	Day	77.3% (11.2%)	0.6% (0.9%)	22.1% (10.9%)
	2 ft/s	Night	90.2% (3.9%)	0.4% (0.8%)	9.4% (4.4%)
	3 ft/s	Day	93.5% (3.5%)	5.6% (2.2%)	0.8% (2.5%)

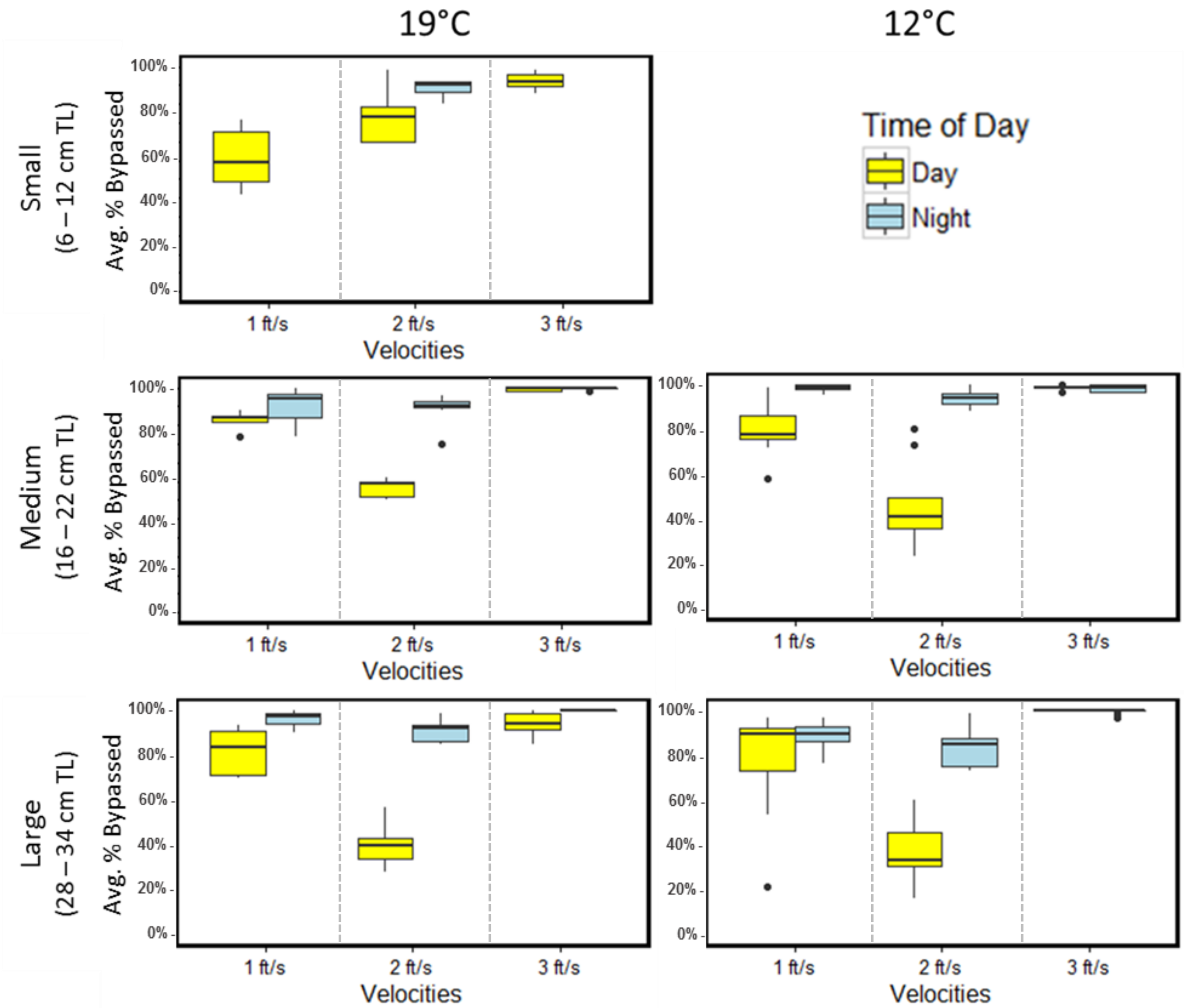

Figure 20. Number of Green Sturgeon collected from the bypass channel during eight replicated trials of each experimental treatment. Trials were conducted with 60 naïve fish. Treatments were planned using a full factorial design of temperature (19°C and 12°C), photophase (Day and Night), water velocity (1, 2, and 3 ft/s), and size class (Small, Medium, and Large). Heavy line indicates median, boxes span from 25%tile to 75%tile (the interquartile range; IQR), and whiskers extend 1.5*IQR. No whisker appears if the minimum or maximum value is equal to the 25%tile or 75%tile, respectively. When points occur beyond whiskers, they are shown. Fish which were not collected in the bypass channel were either entrained through the model louver or remained within the flume for the duration of the experiment.

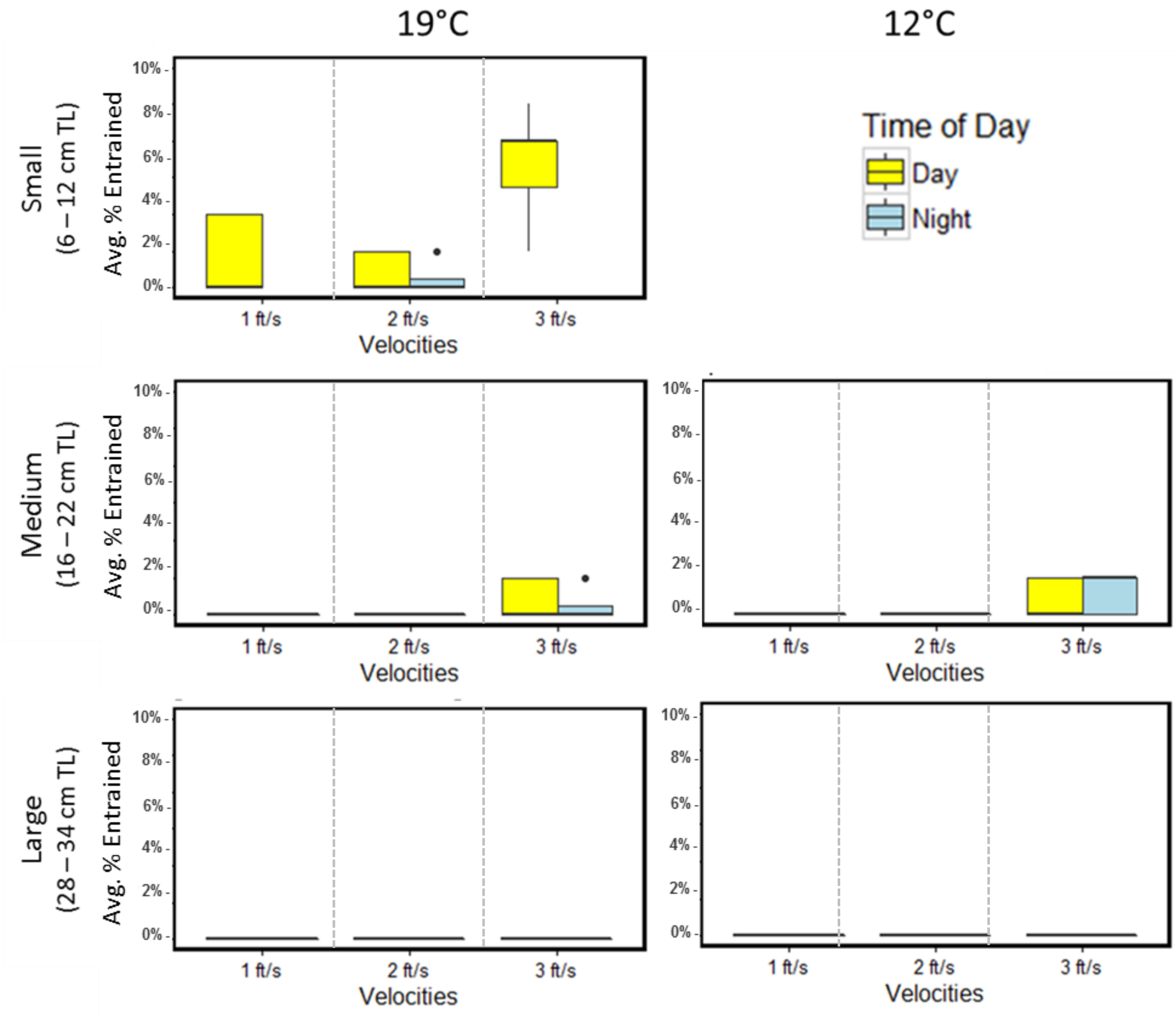

Figure 21. Number of Green Sturgeon entrained through the model louver during eight replicated trials of each experimental treatment. Trials were conducted with 60 naïve fish. Treatments were planned using a full factorial design of temperature (19°C and 12°C), photophase (Day and Night), water velocity (1, 2, and 3 ft/s), and size class (Small, Medium, and Large). Heavy line indicates median, boxes span from 25%tile to 75%tile (the interquartile range; IQR), and whiskers extend 1.5*IQR. No whisker appears if the minimum or maximum value is equal to the 25%tile or 75%tile, respectively. When points occur beyond whiskers, they are shown.

In addition to total number of fish bypassing the louver, we tabulated the number of fish bypassing in each five minute period in all trials. We saw a large number of Green Sturgeon entering the bypass channel in the first five or ten minutes, with a trend for a greater number of fish bypassing earlier in the night-time trials, particularly at lower flow velocities (1 ft/s and 2 ft/s; Figure 22). During the trials at 1 ft/s during the day, the initial pulse of bypassing individuals was much reduced or even absent, and instead we saw a more protracted pattern of bypassing over the course of the trial.

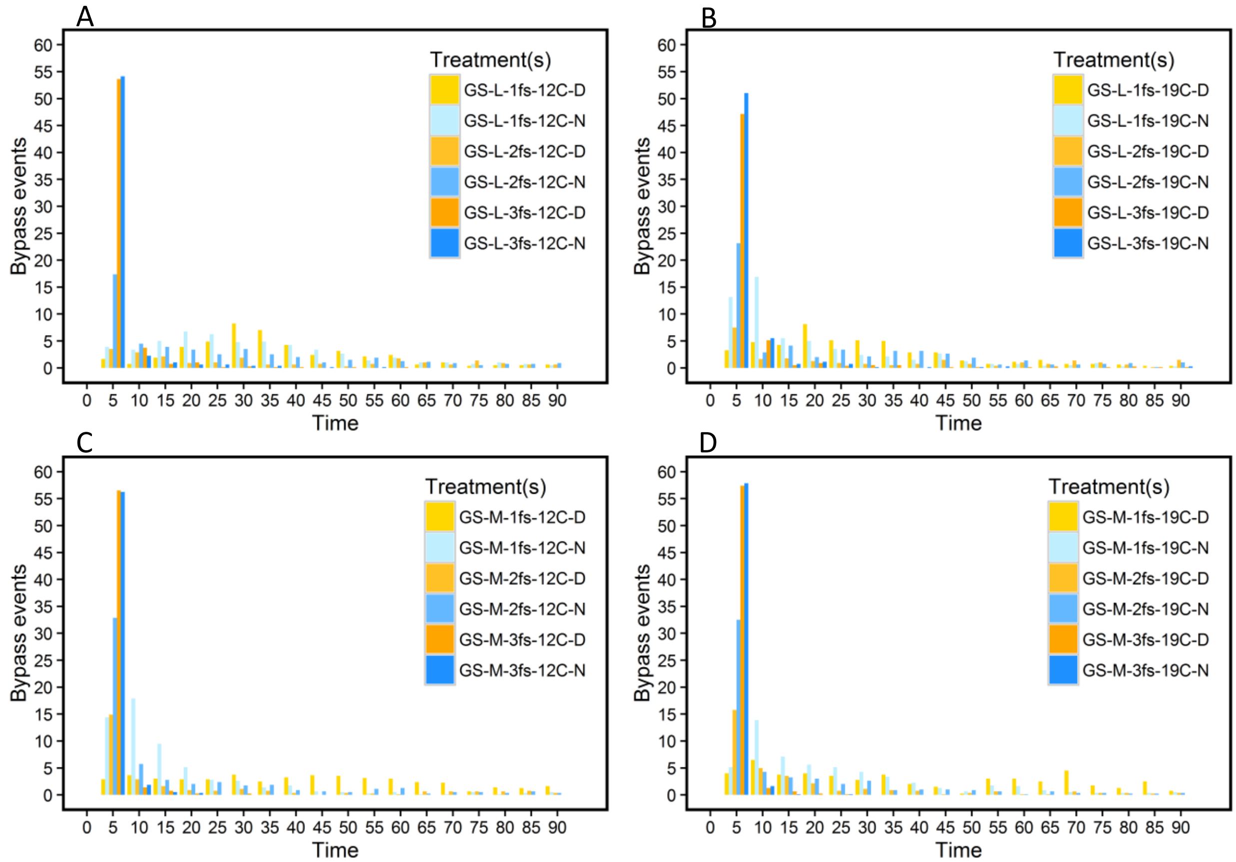

Figure 22. Mean number of juvenile Green Sturgeon (GS) entering the bypass channel in each 5-minute period during the experimental trials. A) all trials of the large size class (L) at 12°C, B) all trials of the large size class (L) at 19°C, C) all trials of the medium size-class (M) at 12°C, and D) all trials of the medium size class (M) at 19°C. Small individuals are not shown because trials have not yet been conducted for all treatments. D=daytime trials; N=nighttime trials; 1, 2, and 3 fs indicates trial water velocities in feet per second.

4.3. Future Plans

We will continue to analyze the underwater video recordings to evaluate rheotaxis upon bypassing as well as the location, type, and extent of louver interactions or entrainment. Findings from these initial video analyses will be used to improve our characterization of sturgeon behavior at the louvers, as well as fine-tuning subsequent data collection. In the coming experimental year, we plan to complete trials with the small size-class of Green Sturgeon, test new IR lighting equipment at night with multiple size classes, build statistical models to evaluate the impacts of the environmental variables tested, and continue video data analysis.

5.0 Predation Assessment Experiments

5.1. Tank, plumbing, and housing

In the 2016 study year we obtained the approval of an amendment for water discharge at the UCD JAHL facility to a different basin. This allowed us to install six 10 ft diameter tanks and associated plumbing to run the predation experiments. Recirculating systems were set up for three pairs of tanks, with each pair sharing a heat pump to control water temperature and a UV light (Figure 23). The systems were operated as partial recirculating systems with a changeover of equivalent water volume every 18 hours. Additional infrastructure was also installed, including overhead supports for shade cloth to reduce glare and algal growth, weatherproof housing for video recording equipment at each experimental tank, and external IR lights for night visibility on video recordings.

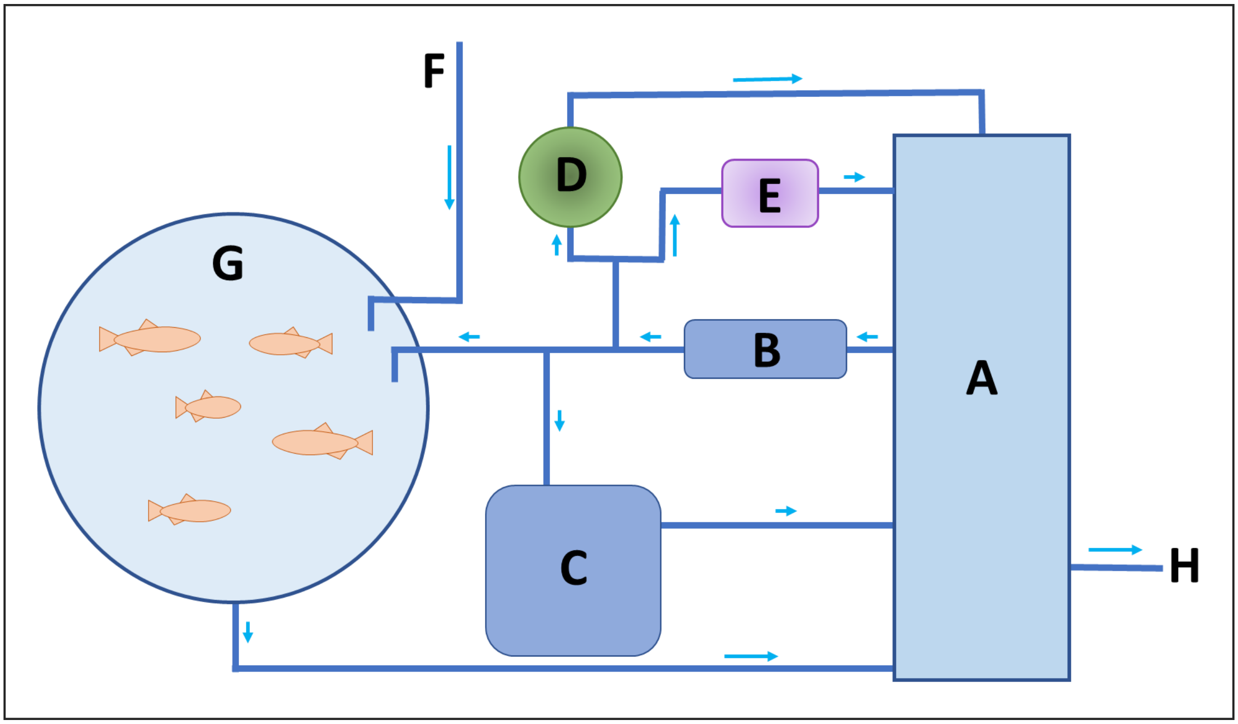

Figure 23. Schematic of the recirculating system, with arrows to indicate direction of water flow. A = sump tank; B = distribution pump; C = heat pump for controlling water temperatures; D = low-head fluidized media biological-filter for detoxifying nitrogenous wastes; E = ultraviolet light sterilizer for fish health and algae control; F = air equilibrated well water inflow to allow 100% make up per day; G = experimental tank with fish; H = overflow discharge to allow for make up replacement.

5.2. Study fish

Largemouth Bass (LMB) were the predator species selected for the 2016 experimental season. Fish were obtained from DWR on May 4, 2016 and assessed for injury or illness. Upon arrival at UCD JAHL, predators were acclimated to 18-19°C well-water and transitioned from live Chinook Salmon to live Rainbow Trout, hatched at UCD. Predators were individually tested to confirm active feeding in captivity. Five large LMB (>40 cm FL; measured size: 43.9 (SD=3.4) cm FL) were available, and these fish were placed into a single experimental tank. An additional four tanks were each populated with five small LMB (<40 cm FL; measured size: 32.9 (SD=2.6) cm FL).

Juvenile Green Sturgeon were hatched on May 2, 2016 and were held at CABA in 450 L circular tanks at 18°C in flow-through air equilibrated well water. They were fed a commercial salmonid diet ad libitum (110% optimum feed rate; Zheng et al. 2014, Verhille et al. 2016). Rainbow Trout (RBT) were selected as the primary alternate prey item to ensure predators were feeding properly between Green Sturgeon trials. Due to limited numbers of RBT, goldfish were used as the alternate prey for a single trial.

5.3. Experimental Design & Protocol

Predation by LMB on Green Sturgeon was assessed by interchanging Green Sturgeon and an alternate prey species every third day (Figure 24). This schedule allowed us to confirm that any observed variation over time in predation rates on Green Sturgeon was not due to loss of feeding behavior in captivity. This also allowed an appropriate period of fasting between trials to avoid predator satiation. A total of eight Green Sturgeon experimental trials were conducted.

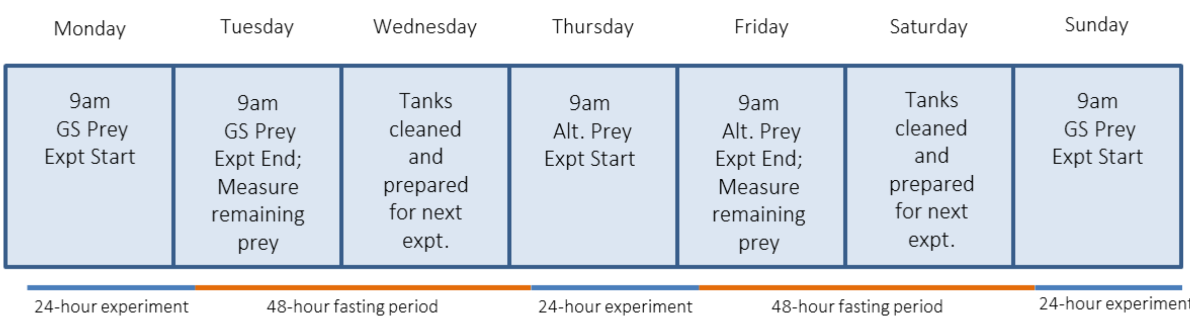

Figure 24. Schematic of an example week during the experimental season, showing the alternation between prey types, the periods of experimental trials, and the periods of predator fasting.

On each experimental day, 150 juvenile Green Sturgeon or the alternate prey species were captured from stock tanks at CABA and roughly size selected to remove extreme outliers in size or fish with deformities. The experimental fish were transported via aerated, insulated coolers to the experimental site at UCD JAHL.Upon arrival, thirty prey fish were added to acclimation cages placed within each 3 m diameter predator tank and held for about 30 minutes. Acclimation cages were approximately 1 m in diameter and consisted of a floated surface and weighted bottom hoop to suspend a columnar net through the full depth of the water column, allowing for acclimation of both pelagic and benthic prey species (Figure 25). This acclimation cage was fine-tuned during the first two trials to decrease opportunities for early prey escape. After the acclimation period the hoops were lifted from the tank to allow the predators and prey to interact for a 24 hour period. Tanks were not disturbed during the trials. Upon completion of the trial, the surviving prey were counted in each tank, then collected and euthanized before being weighed, measured, and assessed for injury.

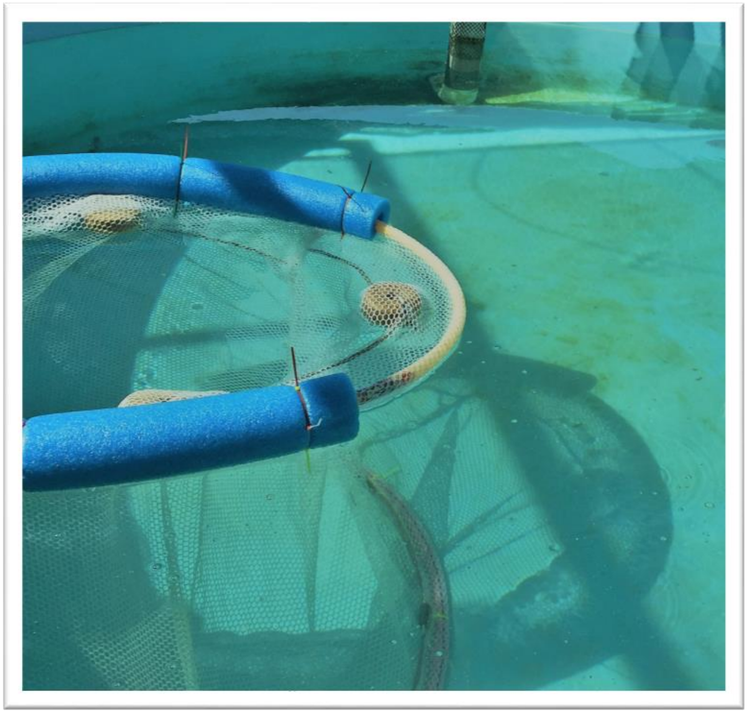

Figure 25. Photo of an acclimation hoop deployed in an experimental tank to allow prey species to acclimate before predation trial began.

Video analysis began after the experimental season was complete and is still ongoing. Analysis will determine the timing of predation events and the rate of predation attempts within the first hour of the experiment. Predation events and predation attempts were also evaluated during two additional one-hour subsets of the experiment, occurring just prior to the end of civil twilight in the evening and just after the beginning of civil twilight in the morning (twilight determined by government charts, approximately 30 minutes before or after true sunset/sunrise). Additionally, rates of predator avoidance, prey rejection, and predator-predator aggression will be recorded from the subsamples of video footage. For alternate prey items, the videos will be analyzed to extract the time until all prey items have been consumed. The results from the video analysis are not yet complete, and thus are not presented here.

5.4. Preliminary results

The first experimental trial of juvenile Green Sturgeon occurred on Jul 4, 2016 (63 days post hatch; DPH) while the last was on Aug 15, 2016 (105 DPH). The mean size of the Green Sturgeon remaining alive after these trials ranged from 9.7 (SD=1.2) to 20.0 (SD=1.8) cm TL (Table 4). Only the size of remaining fish is reported because experimental fish were not weighed or measured prior to the trial to avoid inducing excessive stress and artificially influencing their susceptibility to predation. Fish from a surrogate tank were measured to estimate the mean size of the captive population, but this data has not yet been analyzed.

Table 4. Dates of predation trials, as well as the days post hatch (DPH) of the juvenile Green Sturgeon (GS) and the mean (SD) fork-length (FL) of the Green Sturgeon remaining in the tank after completion of the trial.

Trial	Date	DPH	Mean FL	SD FL
1	Jul 4, 2016	63	9.7	1.2
2	Jul 10, 2016	69	11.0	1.0
3	Jul 16, 2016	75	12.9	1.5
4	Jul 22, 2016	81	14.1	1.4
5	Jul 28, 2016	87	14.7	1.6
6	Aug 3, 2016	93	16.1	2.1
7	Aug 9, 2016	99	18.1	2.2
8	Aug 15, 2016	105	20.0	1.8

There was an overall trend of decreasing mortality of Green Sturgeon as they increased in size (Table 5, Figure 26). There was also a clear difference in the proportion of Green Sturgeon and the alternate prey species consumed by LMB (Figure 27).

Table 5. Mean and standard deviation (SD) of number and proportion of Green Sturgeon (GS) mortalities in each Largemouth Bass predator treatment, as well as corresponding prey consumption rates for paired trials of alternate prey species. There were four replicates of small predators, and a single replicate of large predators. Unless otherwise noted, alternate prey were rainbow trout.

Trial	GS Date	n	Predator size	n GS mortalities	prop GS mortalities	Alt Prey Date	n Alt Prey mortalities	prop Alt Prey mortalities
1	Jul 4, 2016	30	small	6.25 (2.36)	0.208 (0.079)	7/7/2016	30.0 (0.0)	1.00 (0.00)
			large	15.00 (na)	0.500 (na)		30.0 (0.0)	1.00 (0.00)
2	Jul 10, 2016	30	small	10.25 (3.30)	0.342 (0.110)	7/13/2016	30.0 (0.0)	1.00 (0.00)
			large	13.00 (na)	0.433 (na)		30.0 (0.0)	1.00 (0.00)
3	Jul 16, 2016	30	small	4.00 (1.41)	0.133 (0.047)	7/19/2016	30.0 (0.0)	1.00 (0.00)
			large	10.00 (na)	0.333 (na)		30.0 (0.0)	1.00 (0.00)
4	Jul 22, 2016	30	small	4.50 (1.73)	0.150 (0.058)	7/25/2016	30.0 (0.0)	1.00 (0.00)
			large	9.00 (na)	0.300 (na)		30.0 (0.0)	1.00 (0.00)
5	Jul 28, 2016	30	small	2.75 (2.06)	0.092 (0.069)	7/31/2016	30.0 (0.0)	1.00 (0.00)
			large	2.00 (na)	0.067 (na)		30.0 (0.0)	1.00 (0.00)
6	Aug 3, 2016	30	small	1.75 (1.71)	0.058 (0.057)	8/6/2016	27.5 (2.1)	0.92 (0.07)
			large	2.00 (na)	0.067 (na)		30.0 (0.0)	1.00 (0.00)
7	Aug 9, 2016	30	small	0.50 (1.00)	0.017 (0.033)	8/12/2016	27.0 (2.2)	0.90 (0.07)
			large	0.00 (na)	0.00 (na)		30.0 (0.0)	1.00 (0.00)
8	Aug 15, 2016	30	small	0.00 (0.00)	0.000 (0.000)			
			large	0.00 (na)	0.00 (na)			

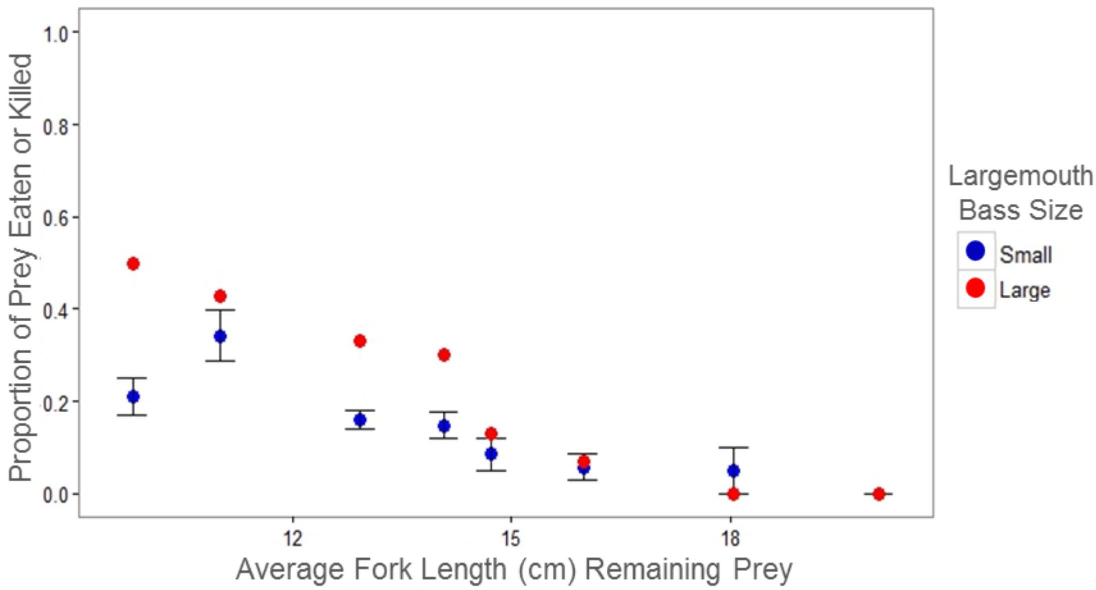

Figure 26. Relationship between mean mortality rates and size of juvenile Green Sturgeon remaining after experimental trials. Color indicates Largemouth Bass predator size. Error bars indicate standard deviations across four tanks of small size-class predators.

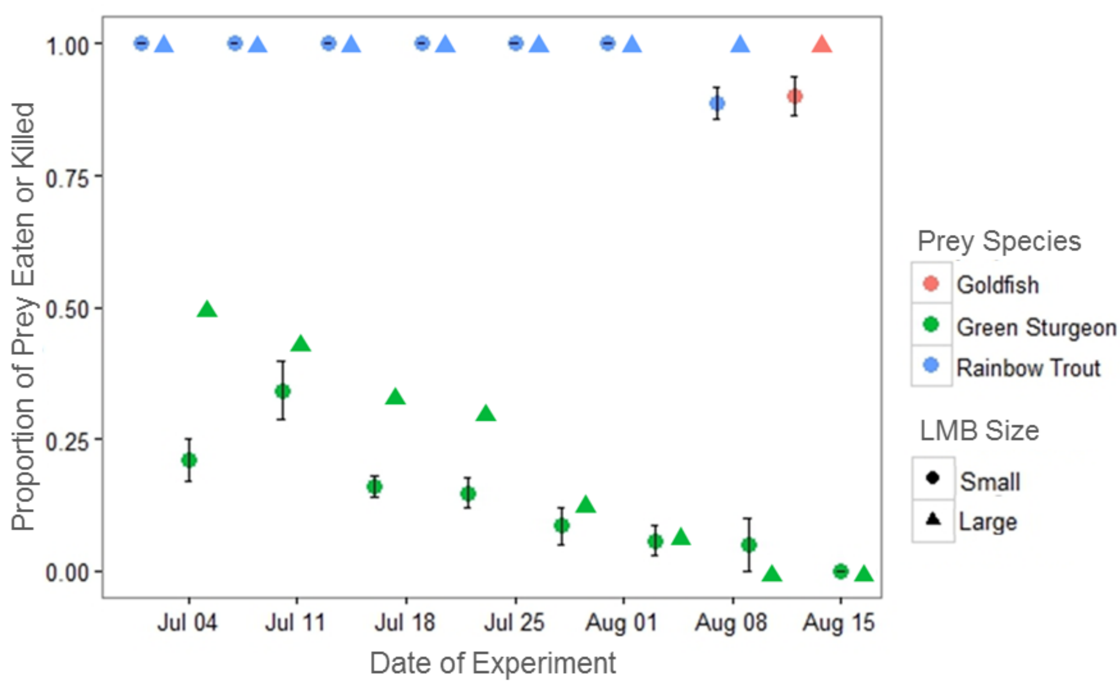

Figure 27. Mean proportion of prey (either Green Sturgeon or an alternate prey species) consumed or killed at each trial date (off-set for visualization purposes). Error bars represent the standard deviation over four replicate tanks, colors indicate prey species, and shape indicates size of Largemouth Bass (LMB) predators.

To evaluate the relative effect of predator and prey size, a general linear mixed model was built (Poisson link function) using the library lme4 (Bates et al. 2015) in the R software package (R Core Team 2016). This model indicated that older Green Sturgeon and those encountering smaller predators had higher survival probabilities (Figure 28). The age of Green Sturgeon juveniles (used as a proxy for size) was a more significant predictor in determining the rate of predation than the size of the Largemouth Bass (Table 6). This is a preliminary model, so results should be evaluated with caution.

Table 6. Parameter estimates for the general linear mixed model used to evaluate the impact of Largemouth Bass predator size and Green Sturgeon age (as a proxy for size) on the predation rates experienced in the experimental trials.

	Estimate	Std. Error	P-value
Intercept	6.56	0.56	<0.0001
DPH	-0.06	0.01	<0.0001
Predator size	-0.55	0.32	0.0866

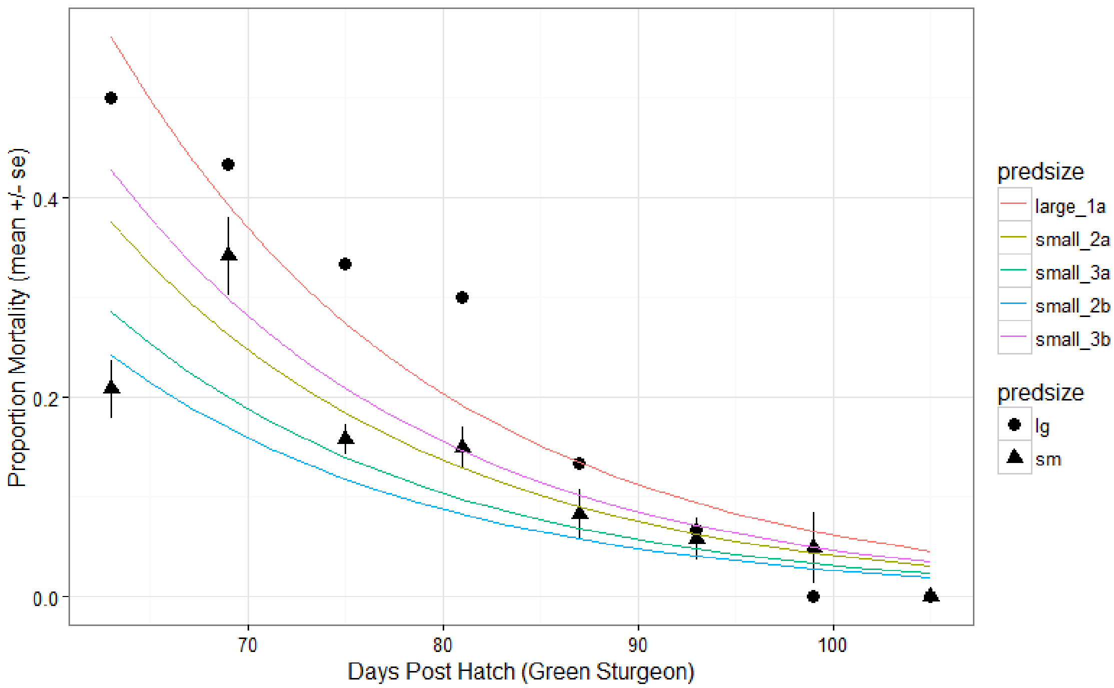

Figure 28. The generalized linear mixed model predictions for proportion of mortality of Green Sturgeon. Predictions are represented as lines, with one shown for each tank. The model was built using GS age (days post hatch) and Largemouth Bass predator size class as predictors, while controlling for the tank ID using a random effect.

5.5. Future Plans

Prior to the next experimental season, we plan to continue video analysis of the 2016 experiments, use pilot data on predation of alternate prey sources to select species for 2017 experimental season, and add additional shading over experimental tanks to reduce algal growth. After successful spawning of the Green Sturgeon broodstock, we will execute experimental trials with Striped Bass (predator #2), and may also evaluate potential housing and alternate prey items for experiments with catfish (predator #3), which are planned for 2018.

6.0 Green Sturgeon Broodstock Status

The juvenile Green Sturgeon used in the 2016 experiments were spawned at UC Davis from one wild-caught female, one wild-caught male, and one male from the existing UC Davis broodstock, following the procedure outlined by Van Eenennmann et al. (2012). Wild-caught adults were provided by the Yurok Tribal Council through a partnership between UCD and the Yurok tribe. The two wild-caught individuals were captured in the Klamath River in the spring of 2016 by tribal members and driven to UCD facilities by our staff for spawning. The spawning procedure involves a natural-type tank spawning over an approximately 24 hour period, with eggs collected every 2 hours throughout. After the eggs are collected, they are transferred into upwelling hatching jars for several days, then moved into glass dishes to sort out infertile eggs. Prior to hatching, the eggs are transferred to well-water and then to UC Davis' CABA facility. At CABA the eggs are distributed between four 450-liter tanks where rearing and exogenous feeding take place. Once on commercial pelleted diet, the sturgeon can be transferred to various tanks for experimental treatments. Fish were kept a minimum of 21 days at 12°C prior to experiments, with an acclimation rate of 1°C/day.

For 2017, we have identified two female and ten male fish from our captive stock with the greatest potential to spawn in the spring. These fish are currently being vernalized with water from Putah Creek for a natural thermal regime.

7.0 Acknowledgements

We gratefully acknowledge the support of the Yurok Tribal Council, their Fisheries Program manager Dave Hillemeier, biologists Michael Belchik and Barry McCovey, and technicians Jamie Holt, Rocky Erickson and Troy Simon Fletcher, for providing the wild-caught broodstock that created the 2016 year class progeny. Additionally, we are thankful for the many hours our laboratory staff, especially Sarah Baird, Trinh Nguyen, and Ryan Shu, have devoted to ensuring the successful execution of these experiments. Finally, there have been numerous undergraduate students who have contributed to completing this work, including Jeff Carter, Rhiannon Follenfant, Heather Bell, Amanda Agosta, Andrew Naslund, Parisa Farman, Ellisa Chapkin, Ryan Young, Megan Hill, Alec Bauer, Blake Friedman, and Paige Mundy.

8.0 Meetings Conducted

UCD scientists both hosted and attended several meetings with DWR staff and scientists. Three Quarterly Meetings took place at the UCD JAHL: the first Quarterly Meeting occurred on March 14th, 2016, the second on June 14th, 2016, and the third on October 13th, 2016. In addition, UCD scientists presented two posters at the Bay Delta Science Conference:

Cocherell et al. Behavior of Green Sturgeon *Acipenser medirostris* Near a Model Louver System in a Laboratory Flume. Poster session presented at: Bay Delta Science Conference; 2016 Nov 15-17, Sacramento, CA.

Carr et al. Hydraulic Conditions Near a Model Louver System in a Laboratory Flume. Poster session presented at: Bay Delta Science Conference; 2016 Nov 15-17, Sacramento, CA.

9.0 Summary

Overall, we had a successful experimental season. We were able to evaluate the velocity fields within the flume at 1 ft/s. To assess louver entrainment, the flume trials are currently ahead of schedule, allowing us to focus on the small size-class of Green Sturgeon in the coming year. We successfully completed the infrastructure for predation assessment trials, developed an effective experimental design, and completed eight full predation trials with Largemouth Bass. We have developed methodologies for analysis of the data we have gathered, and we will continue acquisition of data in the coming months.

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